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AN INVESTIGATION OF CIRCULAR, FINITE QUEUEING SYSTEMS IN AMPHIBIOUS OPERATIONS

by

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Major, United States Marine Corps
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ABSTRACT

The general unloading phase of amphibious operations is examined with particular emphasis on the queueing problems that arise. A model is structured and a computer simulation is provided. Variables considered are the number of transfer vehicles and their speed and payload, the number and capacity of loading and unloading points, and the ship-to-shore distance. Basic relationships between the variables are examined and an approximating formula is developed for computing the time required to unload a given tonnage of cargo. Applications in operational planning, system modification, and total system design are outlined. The impact on system performance of various assumed distributions of travel time and loading time is discussed. For systems employing mixed fleets of transfer vehicles, some basic decision rules are developed as to which vehicles to load or unload first. Suggestions as to further research and as to the model's general applicability are included.

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CHAPTER I

INTRODUCTION AND RATIONALE

One of the key characteristics that serve to distinguish amphibious operations from other types of military operations is the requirement to project forces ashore onto a hostile land mass. This necessitates the rapid and efficient landing of large numbers of men and large quantities of supplies and equipment. Two quite distinct problems are involved. The first is the tactical landing itself, during which the scheduled waves and the on-call serials are landed. The scheduled waves consist of troops and equipment boated in landing craft, amphibians, or helicopters. They are organized into waves and land according to a predetermined time schedule. The on-call serials consist of groupings of troops, equipment, or supplies, for which an early requirement ashore is anticipated. They are called ashore as the need for them arises.

After the scheduled waves and the serials have been landed, the general unloading commences. During the general unloading phase, all remaining cargo and equipment is unloaded from the ships. Landing craft, amphibians, and helicopters, which we shall refer to as transfer vehicles, shuttle back and forth between the ships and the beachhead, bringing ashore the large quantities of supplies necessary to sustain the combat forces which have been landed. This is not a glamorous or exciting phase of an amphibious operation, but the importance of a rapid and efficient build-up of supplies ashore to maintain the momentum of the attack cannot be overlooked.

As the transfer vehicles shuttle back and forth, they may sometimes have to wait at the ship while other vehicles are being loaded.

Likewise, they may have to wait at the beach while other transfer vehicles are being unloaded. The entire system is circular in nature, and may be schematically represented as in Figure 1. In making a cycle, each transfer vehicle may go through six successive stages; the loading queue, the loading operation itself, a transit to the unloading area, the unloading queue, the unloading operation, and a transit back to the loading area. Of course, sometimes an arriving vehicle will find that there is no queue of vehicles waiting to load or unload, as the case may be, and it will move directly into the loading or the unloading operation.

Many factors influence the way in which this system operates, including transfer vehicle speed and payload, the ship-to-shore distance, loading and unloading rates, and the number of transfer vehicles in the system. In analyzing the effects of these various factors, it becomes apparent that we cannot neglect the queueing problems which are inherent in the physical system being considered. Unfortunately, the system which this paper will model does not lend itself to solution by the usual queueing theory methods. The usual queueing theory models assume that arrivals into the system come from some infinite population at a rate which can be measured and in accordance with a probability distribution which can be determined. The system we wish to model, however, involves a finite number of transfer vehicles. Their number may, in fact, be quite small in many actual operations. The rate at which the transfer vehicles arrive at the loading or unloading areas for service is dependent on what is happening at all other stages in the system. Additional complications will arise if we wish to consider the transient period which exists before the system settles down to a steady state. A particularly difficult problem arises from the fact that in practice the fleet of transfer vehicles will often not consist of a single type of vehicle,

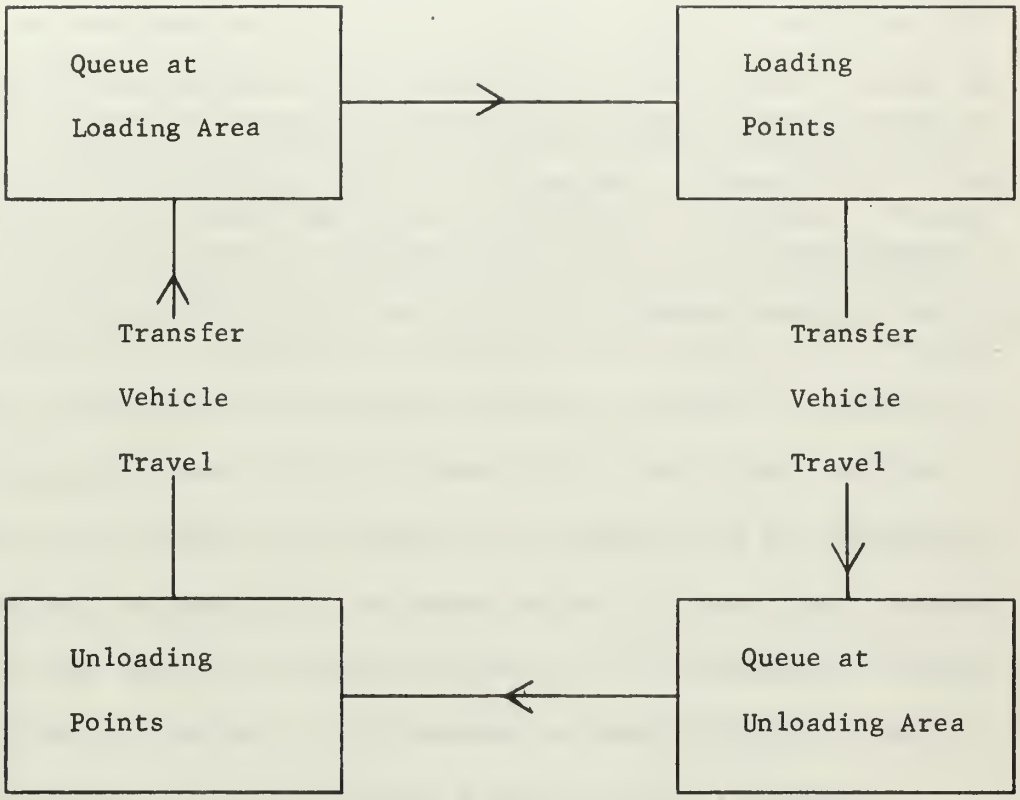


FIGURE 1

Schematic Representation of
General Unloading Operation

but rather will consist of a variety of vehicles, perhaps with widely different operating characteristics.

In this paper we will structure the queueing system and describe and discuss the results of a simulation through which the relationships between several of the variables in this system have been analyzed, and by means of which some of the theoretical questions concerning the nature of this queueing system have been investigated. In a recent paper, Posner[12] presented a closed-form method for computing the steady-state probabilities for queueing systems of the type which we wish to model. However, the computations necessary in his approach are lengthy and solutions are dependent upon the assumption of exponential service rates. A computer simulation, on the other hand, will remove the need for this assumption and also enables us to examine the effect of the transient period at the start of system operation. The computer simulation also permits consideration of various priorities of service when dealing with a fleet of transfer vehicles consisting of a variety of vehicle types.

Chapter II will present a description of the model and the computer simulation will be described in Chapter III. In Chapter IV, results from a series of simulation runs will be presented and analyzed. The parameter values which are used do not correspond to any actual equipment, but are representative of a range of values attainable by existing or proposed equipment. The results serve to demonstrate the type of information that may be generated by the simulation and the general nature of the relationships between the various parameters. An empirically derived formula for estimating the total time to complete the unloading of a given tonnage of cargo will be presented. In Chapter V, the simulation program will be used to test whether the system exhibits the characteristics of a Poisson process, under various

assumptions about the underlying distributions of travel time and service time. An hypothesized mean arrival rate at the loading area will also be tested. This will give us some insight into the nature of the system being studied and will provide us with information as to the significance of the underlying probability distributions on overall system performance. Some results obtained employing mixed fleets of transfer vehicles will be presented in Chapter VI. A summary of results thus far obtained, conclusions, and some comments as to the applicability of the model to other systems completes this paper.

CHAPTER II

DESCRIPTION OF THE MODEL

The physical system we wish to model is the general unloading phase of an amphibious operation. The system may be characterized as containing several key elements. First, there are the ocean-going ships which have transported the landing forces and their supplies and equipment to the objective area. We assume that port facilites are not available for direct unloading onto piers. Next, we have a fleet of transfer vehicles to move the cargo from the ships to the shore. These transfer vehicles may be landing craft, amphibians, helicopters, surface-effect machines, or hydrofoils. In actual operations they will probably exist as a mixed fleet of various types. Whatever their physical characteristics, however, they can be categorized according to their speed and their payload. In this model, we define speed to be a readily attainable cruising speed, rather than the vehicle's top speed. Thus, we may meaningfully speak of a mean time to travel a given distance. We assume that the vehicle's speed is the same, whether it is loaded or unloaded. Payload is taken to be a usable payload, readily achievable when the vehicle is loaded with standardized cargo, such as loaded pallets of uniform size and weight.

Other elements in the system are the cargo-handling facilities on the ships and on the shore. These facilities may also have widely differing physical characteristics, but they can be categorized by their capacity and by the number of loading points. By capacity, we mean their cargo-transfer rate, in tons per hour, achieved when loading standardized cargo into the type of vehicle under consideration. A loading point is defined as a location and a cargo-handling facility

that can accommodate one transfer vehicle at a time. Two possible queues in the system are a queue of transfer vehicles waiting at the ship to load cargo and a queue of transfer vehicles at the unloading area waiting to unload.

Characteristics of the Model.

A complete model of the general unloading operation should include all the steps involved in moving cargo from the hold of a ship to an inland dump, or perhaps all the way to the user. However, the model developed for this study has been simplified in that it considers only a movement of cargo from the ship to an unloading area, which may be thought of as the waterline at the beach, although in the case of amphibian vehicles or helicopters, it might be an inland dump. In either case, we shall assume that the transfer vehicles do not encounter any traffic delays enroute between the ship and the unloading area. The model also assumes that the vehicles cycle continually through the system until all the cargo has been moved. In other words, no allowance is made for refueling or maintenance time during the operation.

In the computation of the loading time or the unloading time for a vehicle, no allowance is presently made in this study for the buffer time, or the time to move a vehicle into position. Buffer time, however, could be taken into account if desired by adding a constant to the computed loading or unloading time. Our computation of loading (unloading) time assumes that the time is a linear function of vehicle payload. This seems reasonable if the cargo to be moved consists of standardized cargo, since the time will be determined largely by the number of slingloads or cycles that the cargo-handling equipment will have to perform. However, this method of computing loading and unloading times may not be completely accurate, since the larger payload

vehicles may be easier to load or unload because of larger loading area, wider hatches, or other physical characteristics. In any comparison of actual vehicles, if one vehicle lends itself to more expeditious loading, then this fact should be taken into account when computing loading or unloading time.

A basic result from queueing theory is the fact that a single queue feeding customers (in this case transfer vehicles) into multiple servicing facilities (in this case the loading or unloading points) will be more efficient than having a separate queue for each servicing facility. Therefore, the model is structured in this fashion, and no provision is made for other arrangements of the queues.

Independent and Dependent Variables.

Among the many variables which affect the system being considered by this model, those which are of principal interest are

1) the number of transfer vehicles,
2) the speed of the transfer vehicles,
3) the payload of the transfer vehicles,
4) the distance the cargo must be moved,
5) the number of loading and unloading points, and
6) the rate at which the cargo-handling facilities can load or unload the cargo.

The model and the associated computer simulation are designed to treat all of these factors as independent variables, that is, values for these variables must be assigned for the program. The principal dependent variables, whose values are the output of the simulation, are

1) the time to complete the unloading,
2) the average waiting times per vehicle round trip,

3) the probabilities that the queues are of various lengths, and

4) the amount of time the loading and unloading facilities are not completely utilized.

As mentioned above, the cargo itself is considered to be standardized cargo consisting of pallets of uniform size and weight, and the model is not designed to consider the effects of variations in the cargo itself. This assumption about the uniformity of the cargo does not seem unreasonable, since the actual cargo involved in general unloading operations consists largely of rations, ammunition, and boxed military equipment, all of which is palletized in a standard and fairly uniform manner.

Measures of Effectiveness.

In this study, the time to complete the unloading of a fixed tonnage of cargo is taken as the basic measure of effectiveness. Any system that takes less time than another system is considered "better" than that other system. Many different combinations of parameter values will produce approximately the same overall results, in terms of time to move a fixed tonnage of cargo. Changing the value of any one of the parameters will change the total time required to complete the operation. In any given situation, total time may be very sensitive to changes in one or more of the parameters and relatively insensitive to changes in other parameters. Trade-offs exist among the six independent variables which we are considering.

In a study of broader range, of course, we would be interested not only in the time to complete the unloading operation, but also in the cost. However, it will not be possible to simultaneously minimize time and cost, since it appears that a higher cost system (say, a system

with more transfer vehicles) will always achieve at least some reduction in time. Therefore, it will be necessary to minimize the cost to complete the unloading in a given time, or to minimize the time to complete the operation for a fixed cost.

Using time as the basic measure of effectiveness seems intuitively appealing, since time is certainly of the essence in an amphibious operation. Other possible measures of effectiveness, such as average queueing time or utilization rate of the cargo-handling facilities, do not appear to be of central importance. At any rate, their impact on system performance could be taken into account by extending the study to the costing of alternative systems.

CHAPTER III

DESCRIPTION OF THE COMPUTER SIMULATION

The computer simulation written for this study is and event-store simulation written in FORTRAN IV for the IBM 360/67. Program documentation is included in the appendices. Throughout the program, the time required to complete an event is computed in the following fashion. First, a random number is selected from a uniform distribution, using the IBM library subroutine RANDU. The resulting uniform random number is then transformed to the desired probability distribution. For example, in the case of a transformation from a uniform random number y to an exponentially distributed random number x, the formula is $x=(-1/L)(\ln y)$, where $1/L$ is the mean of the exponential distribution. The number thus computed is then added to current time to obtain the time at which the event in question will occur. This time of occurrence is then stored in an array indexed by vehicle number.

The program consists of seven major parts:

1) the starting routine,
2) the executive routine,
3) arrival at the loading area,
4) arrival at the unloading area,
5) departure from the loading area,
6) departure from the unloading area, and
7) the ending routine.

In the starting routine, constants and arrays are initialized and parameter values are assigned to the independent variables. The simulation is started by placing all the transfer vehicles in the loading queue at

the ship, moving as many as possible into the loading points, and computing the time at which loading will be completed for each of the vehicles being loaded.

The second part of the program, which corresponds to an executive routine, searches through the arrays in which the occurrence times have been stored and selects the minimum time. This is the next event to occur, and can be one of four possibilities; an arrival at the loading area, an arrival at the unloading area, a departure from the loading area, or a departure from the unloading area. If the next event is an arrival at the loading area, the program checks the length of the queue and then the status of the loading points. If a queue exists, or if all loading points are occupied, the arriving vehicle goes into the queue. Otherwise it moves directly into an unoccupied loading point and a time for completion of loading is computed and stored. Arrivals at the unloading area are treated in the same fashion as arrivals at the loading area.

If the next event is a departure from the loading area, a transit time is computed and stored. The program then brings a vehicle from the queue into the loading point, or if no queue exists, sets the status of the loading point to empty. Departures from the unloading area are treated in the same fashion as departures from the loading area. Throughout the program, whenever queue length changes, the program computes the time the queue has been of a given length.

When a specified quantity of cargo has been moved through the system, the program goes to its ending routine and computes and prints the data for that run. The output consists of the values of the dependent variables, as described earlier, together with identifying information for ease in analyzing the results. Modifications to the basic

program to accomplish specific tasks or to accumulate specific data will be discussed in the sections concerned with the special problems necessitating those changes.

CHAPTER IV

DEVELOPMENT OF AN APPROXIMATING EQUATION FOR TIME REQUIRED TO UNLOAD A GIVEN TONNAGE OF CARGO

As has been explained previously, the time required to complete the unloading of a fixed tonnage of cargo is the basic measure of effectiveness being used in this model. Six independent variables are being considered: the distance the cargo must be moved, the speed, the payload, and the number of transfer vehicles, the number of loading and unloading points, and the capacity of the loading and unloading points. Total tonnage of cargo to be moved is held constant at 10,000 tons throughout this paper, although the tonnage may easily be varied in the computer simulation. The simulation is structured as a balanced system, that is, with an equal number of loading and unloading points of equal capacity. Intuition, theory, and previous studies (ref. 1) all support the notion that an unbalanced system will not provide a desirable or "efficient" system. If, for instance, the total capacity of the loading points is greater than the total capacity of the unloading points, transfer vehicles will tend to queue up waiting to unload, thus producing inefficient utilization of the transfer vehicles. The loading points will be working at far less than their capacity, also, thus producing an inefficient overall system.

In order to generate data for analysis, a number of computer runs were made with various values assigned to the independent variables. The number of loading and unloading points was held constant at four each. Fleets consisting of eight, twelve, and sixteen transfer vehicles were considered. Four values of transfer vehicle speed were considered, in conjunction with four values of ship-to-shore distance,

as shown in Table I. In the computer simulation itself, only the mean travel time is used. Therefore we were able to consider all sixteen combinations of speed and distance by considering only seven mean travel times.

TABLE I

Mean Travel Times Utilized in Simulation Runs

	Ship-to-shore Distance			
Speed	2.5 miles	5 miles	10 miles	20 miles
5 knots	0.5 hrs.	1.0 hr.	2.0 hr.	4.0 hr.
10 knots	0.25 hr.	0.5 hr.	1.0 hr.	2.0 hr.
20 knots	0.125 hr.	0.25 hr.	0.5 hr.	1.0 hr.
40 knots	0.0625 hr.	0.125 hr.	0.25 hr.	0.5 hr.

The mean capacity of each of the loading and unloading points was taken to be fifteen tons per hour, which appears to be in the range of the actual capacity of presently used equipment. Vehicle payloads considered were five, ten, fifteen, and twenty tons. For these runs, the underlying distribution of both service (loading or unloading) and travel times was assumed to be exponential. Chapter V discusses some results obtained using other assumed distributions.

Portions of the sample data are presented graphically in Figures 2, 3, 4, and 5. In all of these figures, the principal dependent variable, time, is plotted on the vertical axis. This is the time to complete the movement of ten thousand tons of standardized cargo from the ships to the shore. In any graphical presentation of the data, only one or at most two of the independent variables can be displayed conveniently in a single figure. In both Figures 2 and 3 the ship-to-shore distance is held constant at five miles, the number of

loading and unloading points is held constant at four each, and their mean capacity is held constant at fifteen tons per hour. In Figure 2, transfer vehicle speed is also held constant at ten knots and vehicle payload is plotted against time. Three separate curves are shown for various values of N, the number of transfer vehicles in the system. It is readily apparent from Figure 2 that, other things being equal, larger payload vehicles are more efficient than small payload vehicles. However, it is also apparent that the marginal returns from increasing vehicle payload diminish very rapidly. For a fleet of 12 vehicles, under the conditions portrayed by this figure, the marginal returns achieved by increasing vehicle payload from 5 tons to 10 tons are fairly substantial. Time to complete the operation is reduced from 287 hours to 215 hours, for a gain of 72 hours. However, the marginal return achieved by increasing payload from 10 tons to 15 tons is only 18 hours, and the marginal return achieved by increasing payload from 15 tons to 20 tons is an insignificant 3 hours.

In Figure 3, vehicle payload is held constant at 5 tons and vehicle speed is plotted against time. Again, three curves are shown, corresponding to 8, 12, and 16 vehicles in the system. Increasing vehicle speed from 5 knots to 10 knots produces impressive reductions in the total time necessary to move 10,000 tons of cargo through the system. Increasing vehicle speed from 10 to 20 knots produces a substantial reduction in time for the fleet of 8 vehicles and lesser reductions for the fleets of 12 and 16 vehicles. As we increase vehicle speed above 20 knots, however, the marginal returns diminish almost to the vanishing point, as evidenced by the essentially horizontal shape of the curves between 20 knots and 40 knots. For the fleet of 16 vehicles, there is almost no time reduction achieved by

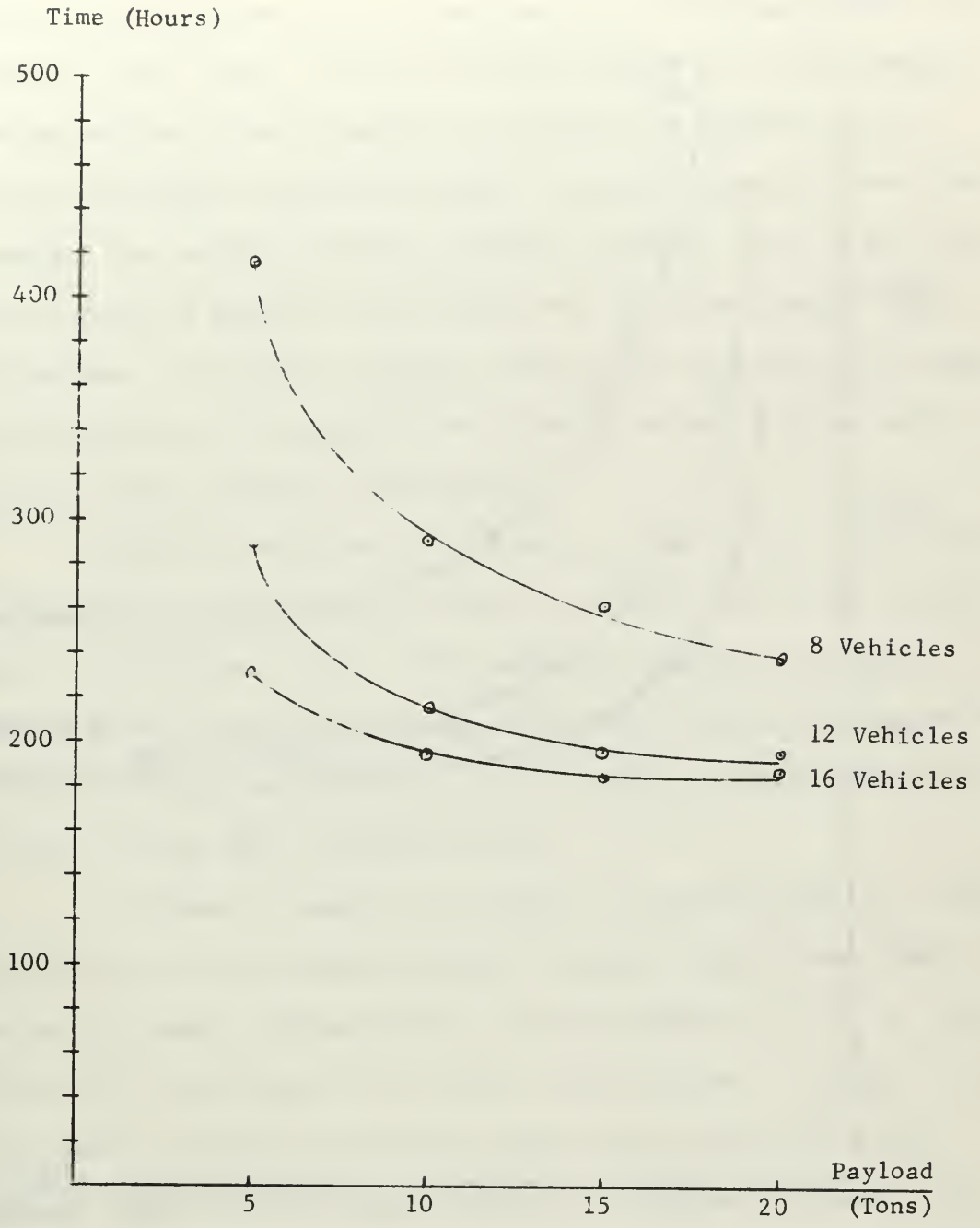


FIGURE 2

Time to Unload Ten Thousand Tons of Cargo versus Transfer Vehicle Payload (Distance 5 Miles, Speed 10 Knots)

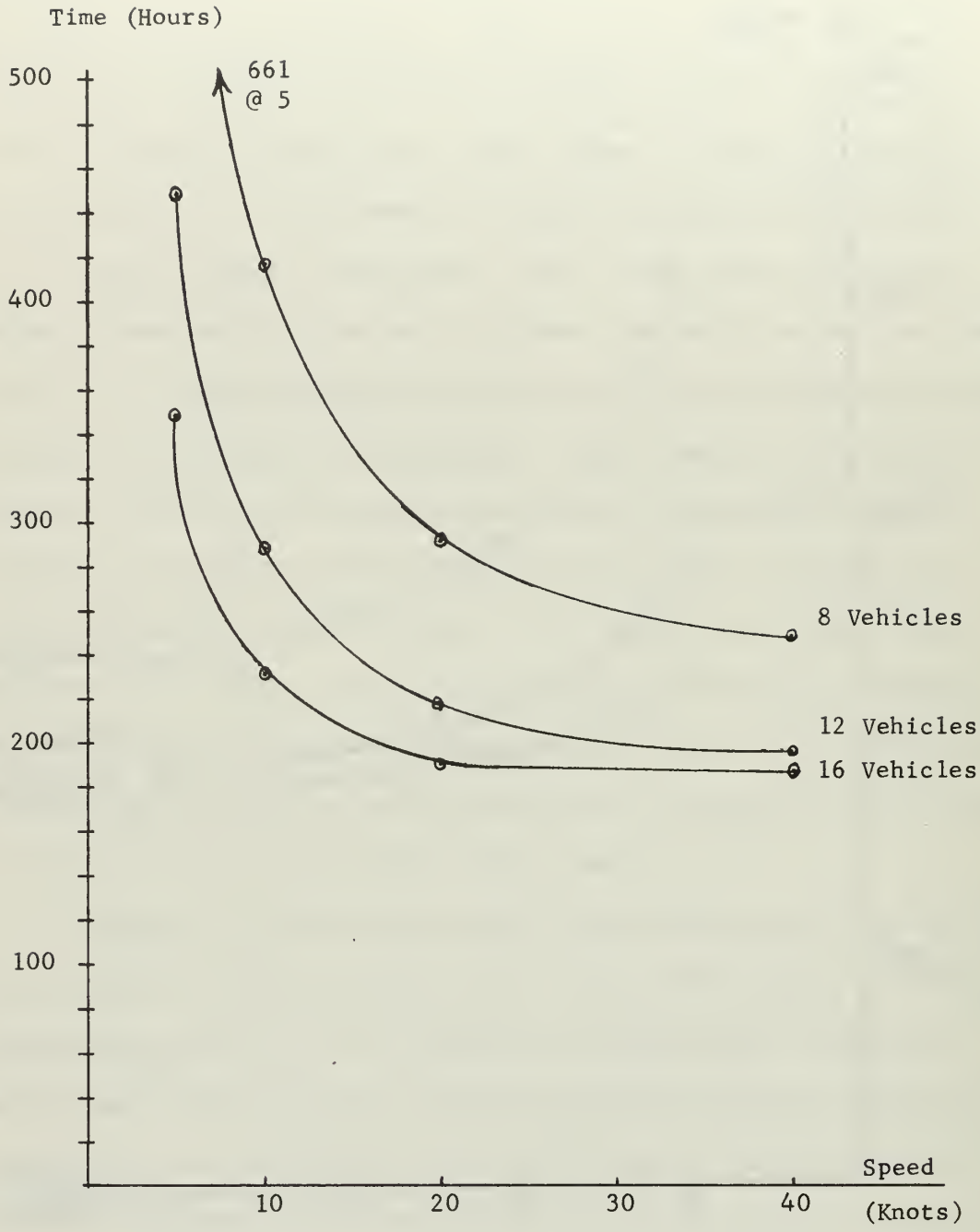


FIGURE 3

Time to Unload Ten Thousand Tons of Cargo versus Transfer Vehicle Speed (Distance 5 Miles, Payload 5 Tons)

increasing speed from 20 to 40 knots under the set of conditions portrayed in this figure. We would normally expect to encounter diminishing marginal returns whenever we increase one parameter while holding the other parameters constant. In this system, however, the marginal returns from increasing vehicle payload, speed, or the number of vehicles diminish very rapidly once the queue lengths begin to increase. Conversely, marginal returns from increasing the number or the capacity of the loading and unloading points are very small when the queues are not in existence.

Figures 4 and 5 are of a slightly different type. Total time to unload ten thousand tons of cargo is again plotted on the vertical axis, as in Figures 2 and 3. The number of loading and unloading points is held constant at 4 each, their capacity is held constant at 15 tons per hour, and the ship-to-shore distance is held constant at 5 miles, as was done in Figures 2 and 3.

In Figure 4, however, the number of transfer vehicles is held constant at 12, and vehicle payload is plotted against time. Four curves are shown, corresponding to vehicle speeds of 5, 10, 20, and 40 knots. In the figure, S is used to denote speed. In Figure 5, the number of transfer vehicles is again held constant at 12 and vehicle speed is plotted against time. Four curves are shown, corresponding to vehicle payloads of 5, 10, 15, and 20 tons. In the figure, P is used to denote payload. The curves in Figures 4 and 5 display the same general shape as the curves in Figures 2 and 3. Again, the curves flatten out rapidly as we proceed from lower to higher values of the independent variables, reflecting the rapidly diminishing marginal returns which are characteristic of this system.

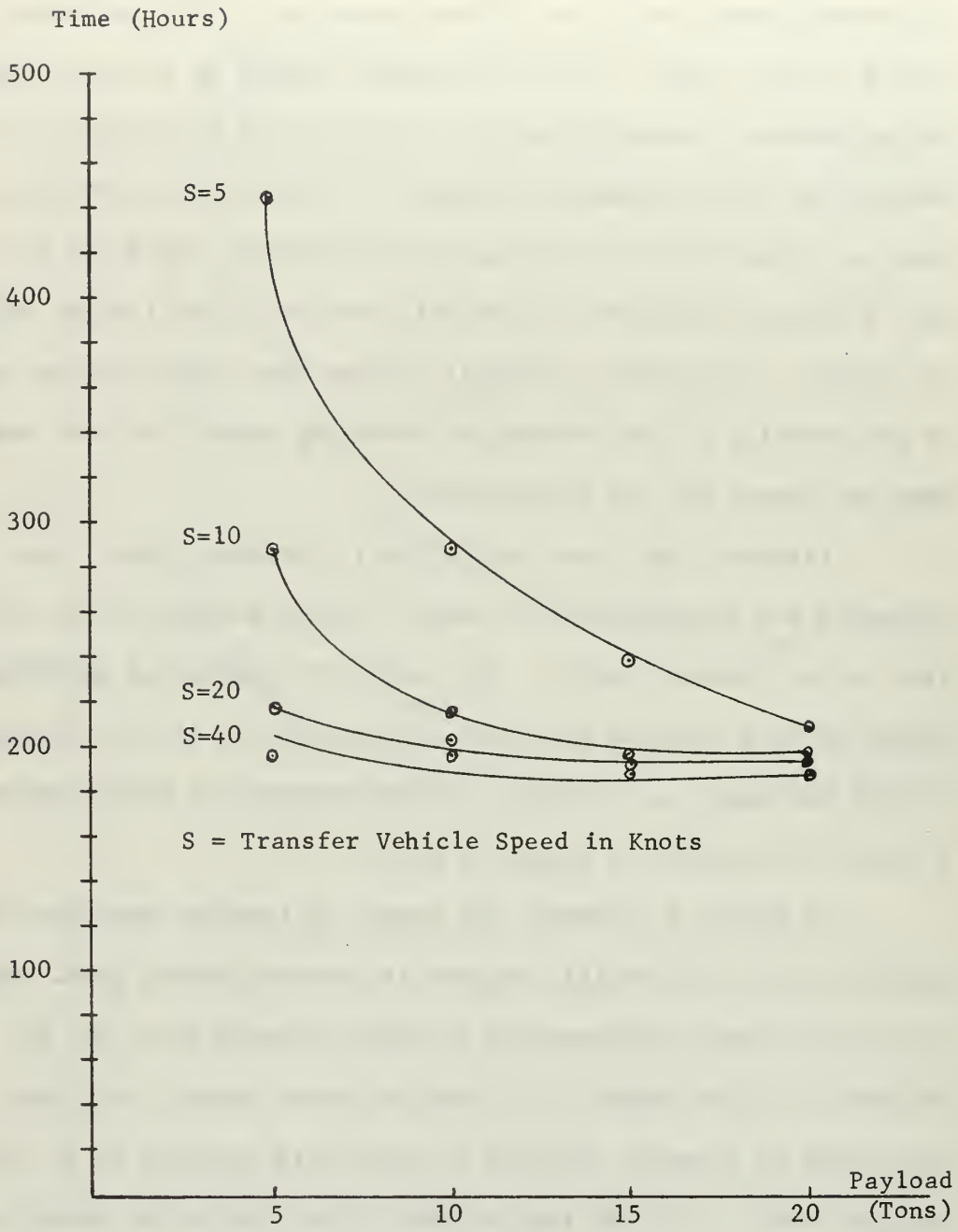


FIGURE 4

Time to Unload Ten Thousand Tons of Cargo versus Transfer Vehicle Payload (Distance 5 Miles, 12 Vehicles)

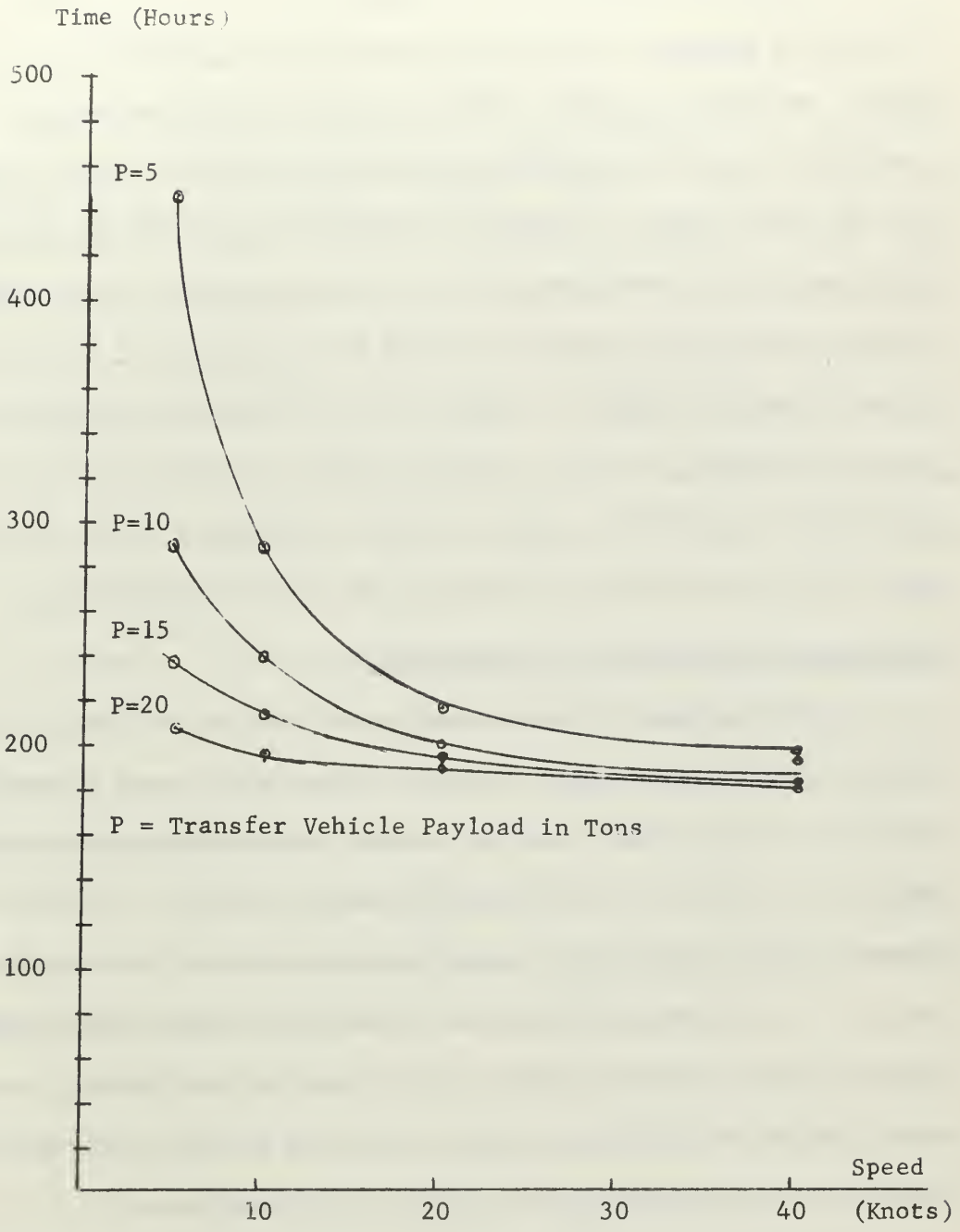


FIGURE 5

Time to Unload Ten Thousand Tons of Cargo versus Transfer Vehicle Speed (Distance 5 Miles, 12 Vehicles)

All of the foregoing leads immediately to the realization that, in order to create an "efficient" system, or to improve on an existing system, we need to consider several variables simultaneously. The complexity of the relationships between the variables under discussion and the large number of possible combinations of parameter values that might have to be investigated lead to the conclusion that a simple function relating the variables would be of use even if it were only an approximating formula. Computational ease might compensate for lack of exactness, and once the approximating formula has led us to an "efficient" neighborhood, more detailed investigations can be carried out in this neighborhood by means of the computer simulation.

Development of an Approximating Equation.

In developing an approximating formula, it will be useful to start from a highly simplified model, from which a more sophisticated model may be developed. Let us consider a system in which the times required to load or unload a vehicle and the time for a vehicle to travel a given distance are known constants, rather than random variables. We will refer to this as a system with determinate times, or simply as a determinate system. Let us also assume that it is a balanced system, as discussed earlier, and that the fleet of transfer vehicles is composed entirely of vehicles of one type.

For a balanced, determinate system the computation of total time to move a given tonnage of cargo through the system is fairly simple. We can readily design a balanced, determinate system in which there will be no queueing time. The total time to complete the movement of a given tonnage of cargo through such a system can then be determined as follows. Let T be the total tonnage of cargo

to be moved, let P be the payload of an individual transfer vehicle, D the ship-to-shore distance, S the speed of a transfer vehicle, N the number of transfer vehicles, and L the capacity of an individual loading (or unloading) point. Then the number of vehicle round trips required is the tonnage divided by the vehicle payload, or T/P. The number of round trips per vehicle is then T/NP. The one-way travel time is the ship-to-shore distance, D, divided by vehicle speed, S. The time required for a vehicle to make one round trip will be twice the one-way travel time plus the loading time plus the unloading time. Loading time and unloading time are assumed to be equal and are given by vehicle payload, P, divided by L, the capacity (in tons per hour) of an individual loading or unloading point. Thus the time required for a vehicle to make one round trip is $2(D/S + P/L)$. Multiplying round trip time by the number of round trips required per vehicle gives us approximately the total time required.

$$\text{Time} = 2(T/NP)(D/S + P/L). \qquad (1)$$

The formula is approximate in this case only because of the transient period at the start and at the end of system operation.

Equation (1) assumed that we had designed a system in which the transfer vehicles never had to wait to load or to unload. A queue can develop in a determinate system with homogeneous vehicles only if the time required for a vehicle to travel to the unloading area, unload, and travel back to the loading area is less than the time required to load the remaining N-1 vehicles. The time required for a vehicle to travel to the unloading area, unload, and travel back to the loading area is given by $2D/S + P/L$. The time required to load the remaining N-1 vehicles is $(N-1)(P/L)$ if we have one loading point. Only one queue will form in a balanced, determinate system, and since we started all

the transfer vehicles at the loading area, the one queue will be at the loading area. Q, the amount of queueing time per vehicle round-trip, is given by

$$Q = (N-1)(P/L) - (2D/S + P/L). \qquad (2)$$

If Equation (2) gives a negative value for Q, queueing time per vehicle round trip will be zero.

Now consider a balanced determinate system with multiple loading and unloading points. Let K represent the number of loading points. Since we are dealing with a balanced system, K also represents the number of unloading points. We will assume that all loading points operate until the ship as unloaded, and that transfer vehicles depart and arrive in groups of K vehicles. A queue can develop only if the first group of K vehicles can travel to the unloading area, unload, and return to the loading area before the remaining N-K vehicles have been loaded. The time required to load the remaining N-K vehicles will be given by ((N-K)/K)(P/L), and an approximate equation for queueing time per vehicle round trip in this system will be

$$Q = \frac{(N-K)}{(K)} (P/L) - (2D/S + P/L). \qquad (3)$$

By multiplying and grouping terms, we can rewrite this equation in the more convenient form

$$Q = \frac{NP}{LK} - 2(D/S + P/L).$$

We are now ready to consider the more realistic case of a stochastic model, in which the times for loading, unloading, and travel are random variables rather than constants. The amount of queueing time per vehicle round trip also becomes a random variable. We wish to develop a simple approximating equation for determining the average queueing time per vehicle round trip, which we shall denote by X. It

seems reasonable to suppose that the average queueing time per vehicle round trip for the stochastic model is related in some way to the queueing time per vehicle round trip for the determinate case. Values for Q, the amount of queueing time per vehicle round trip for the determinate model, were computed for a number of combinations of parameter values. Equation (3) was used for these computations. Values for X were then determined for the same combinations of parameters by means of the computer simulation. A least squares curve was then fitted to the data points. The relationship thus derived between X and Q is given by

$$X = 0.19Q^2 + 0.69Q + 0.37. \qquad (4)$$

The root mean square error was 0.0456. This approximation gives reasonably accurate estimates of X for values of Q in the range from - 0.5 hours to + 1.5 hours. A negative value for Q indicates that in a determinate system there would be no queue and the loading and unloading points would be unoccupied some of the time. Thirty data points were used in fitting the least squares curve. Table II shows the parameter values used, the average queueing time per vehicle round trip as determined by the computer simulation, and the average queueing time per round trip as determined by Equation (4).

If the value of Q computed by Equation (3) is less than - 0.5 hours, this suggests that the loading and unloading facilities are standing idle much of the time. If the computed value of Q is greater than 1.5 hours, the transfer vehicles are spending an inordinate amount of time waiting to load or to unload. In either case, the overall system operation would probably be considered inefficient. Thus, the range in which we will be primarily interested when applying the equation will be the range covered by Equation (4), namely - 0.5 to + 1.5.

TABLE II

Average Queueing Time per Vehicle Round Trip:
Comparison of Simulation Results and
Results Computed by Approximating Equation

Mean Loading Time	Mean Travel Time	Number of Vehicles	Time from Simulation	Time from Equation
.06 Hr.	.33 Hr.	8	.08 Hr.	.29 Hr.
.06	.33	12	.35	.52
.06	.33	16	.67	.78
.12	.33	8	.06	.21
.12	.33	12	.26	.38
.12	.33	16	.56	.70
.25	.33	8	.03	-0-
.25	.33	12	.15	.26
.25	.33	16	.36	.49
.50	.33	16	.15	.16
.06	.67	8	.24	.29
.06	.67	12	.81	.80
.06	.67	16	1.45	1.48
.12	.67	8	.18	.21
.12	.67	12	.77	.70
.12	.67	16	1.32	1.35
.25	.67	8	.12	-0-
.25	.67	12	.53	.49
.25	.67	16	1.18	1.08
.50	.67	12	.27	.16
.50	.67	16	.74	.62
.06	1.0	8	.36	.29
.06	1.0	12	1.17	1.12
.12	1.0	8	.37	.21
.12	1.0	12	1.14	1.00
.12	1.0	16	2.04	2.17
.25	1.0	8	.30	-0-
.25	1.0	12	.95	.76
.25	1.0	16	1.96	1.83
.50	1.0	12	.61	.37

The average time for a vehicle to complete a round trip in the stochastic model will be the sum of average travel times, average loading and unloading times, and X, the average queueing time per vehicle round trip. Average time per round trip, then, will be given by

$$2(D/S + P/L) + (X).$$

Total time required to unload a given tonnage of cargo will be approximately the time per vehicle round trip multiplied by the required number of round trips per vehicle, or

$$\text{Total Time} = 2(D/S + P/L)(T/NP) + (X)(T/NP), \qquad (5)$$

where X is given by Equation (4).

Application of the Approximating Equation.

An application of the approximating equation would be to estimate the performance of a given ship off-loading system. The need for such an estimate might easily arise in the course of operational planning. In the same context of operational planning, we may perhaps find ourselves able to vary only one or two of the parameters which are treated as variables in this model. The approximating equation will provide us with a ready means of estimating how changes in these parameters will affect the time required for the general unloading. In a somewhat longer time frame, we may be faced with a choice between several proposed systems. We could use either the computer simulation itself or the approximating equation to obtain estimates of the performance of each of the alternative systems. We would then be able to choose the system that provides the best performance in relation to its cost.

We have outlined the use of the computer simulation or the approximating equation in estimating the performance of a given system or in choosing between a given group of alternative systems. Another situation with which we may be faced is the task of determining the best way in

which to modify an existing system. By use of the approximating formula or the computer simulation we can estimate the reduction in time to be expected from incremental changes in each of the variables. If we also knew the additional cost associated with the proposed change in each variable, we could then select which variable to modify in order to achieve the largest reduction in time for a given cost.

Suppose we are given a system in which the parameter values are as follows: the number of transfer vehicles, N, = 12, the speed of the transfer vehicles, S, = 10, the payload of the transfer vehicles, P, = 5, the number of loading points, K, = 4, the capacity of the loading points, L, = 15, and the ship-to-shore distance, D, = 5. From the data generated by the computer simulation we obtain an estimate of 287 hours required to move ten thousand tons of cargo through this system. For simplicity, suppose we wish to consider two possible changes in the system: first, a change in the payload of the twelve vehicles from five to ten tons, and second, a change in the number of five-ton payload vehicles from twelve to sixteen. Let us further suppose that the additional costs associated with these two changes are equal. We wish to determine which of the changes to implement in order to achieve the largest reduction in time. Changing the number of vehicles in the system from twelve to sixteen reduces the estimated time for completion of the unloading to 229 hours. Changing the payload of the twelve vehicles from five tons to ten tons reduces the estimated time to 215 hours. In this hypothetical situation we would choose to increase vehicle payload rather than adding more vehicles to the system.

A far more complex problem arises if we wish to design a complete system. There does not appear to be any global optimum in the system we are modeling. Decreasing ship-to-shore distance or increasing any one

of the other variables always seems to result in at least some reduction in the time required to land a given tonnage of cargo. We can strive to design a system to accomplish the unloading in a minimum amount of time for a given cost or to accomplish unloading at a minimum cost in a given time.

For illustrative purposes, suppose we wish to minimize the cost to land a given tonnage of cargo in a fixed amount of time. It appears that the most practical procedure would be simply to enumerate the combinations of parameter values that produce the desired result in terms of time to complete the landing of a given tonnage of cargo. This would appear to be a sizable task. However, the number of transfer vehicles in the system and the number of loading and unloading points clearly must be integer values. The speed and payload of the transfer vehicles and the capacity of the loading points might be thought of as continuous variables, but in practice we need only concern ourselves with a reasonable number of values for these variables. We might, for instance, consider five-ton increments in transfer vehicle payload. Even so, we will have to examine many combinations of parameter values. Fortunately, a computer can solve the approximating equation very rapidly and can readily be programmed to eliminate all combinations that do not meet our time criterion. Many combinations can be eliminated almost automatically. For instance, if we find a set of parameter values including a fleet of twelve vehicles that will meet our unloading time criterion, we would not want to consider systems using larger numbers of transfer vehicles in conjunction with the same set of values for the other parameters. Rough cost data should further serve to reduce the number of alternatives to manageable proportions. For this reduced number of alternatives we can then make

more detailed cost estimates and select the system that will accomplish the task at a minimum cost.

We have developed an approximating equation for estimating the time required to land a given tonnage of cargo, and we have outlined how this equation or the computer simulation may be used in operational planning, in choosing between proposed alternative systems, and in determining how best to modify an existing system. We have also described a procedure which offers a possible approach to the complex problem of total system design. A number of questions still remain, however. The data for the analysis in this chapter was based on the assumption of the exponential distribution for both service and travel time. The question of how this assumption affects system performance will be examined in Chapter V. In Chapter VI, we will examine some of the implications of having a fleet of transfer vehicles composed of more than one type of vehicle.

CHAPTER V

TESTING THE CHARACTERISTICS OF THE SIMULATION MODEL

A considerable amount of theoretical and practical work has been done on networks of queues and on queues in tandem.[8] This work generally assumes the existence of an independent stochastic process producing inputs or arrivals to the queueing network. Frequently, it is assumed that these arrivals occur in accordance with a Poisson distribution. Because of the circular nature of the physical system which we are attempting to model, however, there is no independent input into the system. Rather, once the system is in operation the arrival rate at any point in the system is dependent on the output of the rest of the system. In order to gain some insight into the operation of the system and to determine whether changes in the underlying distributions of travel time and service time affect the operation, we will test two hypotheses about the system. First, we will test the hypothesis that the vehicles cycling through the system arrive at the loading area in accordance with a Poisson distribution. Secondly, we will test an hypothesis concerning the mean arrival rate.

Testing Whether the System Is of the Poisson Type.

In order to test whether arrivals at the loading area occur in accordance with a Poisson distribution, a means for measuring the arrival times at the loading area was inserted into the computer program. We wish to measure the amount of time, T, required to observe n arrivals.[10] We will denote the time from the start of measurement until the i^{th} arrival as U_i. If the arrivals have occurred in accordance with a Poisson distribution, then the random variables $U_1, \ldots,$ U_n are independent and uniformly distributed over the interval (0,T).

Since the number of observations, n, varied from five hundred to two thousand, we may use the central limit theorem to assert that the sum,

$$S_n = \sum_{i=1}^{n} U_i,$$

of n independent random variables, each uniformly distributed on the interval 0 to T, may be considered to be normally distributed with t mean $n(T/2)$ and variance $n(T^2/12)$. At a 95 per cent level of significance, then, we could accept the hypothesis that the arrivals are in accordance with a Poisson distribution if the following inequalities are satisfied:

$$n(T/2) - (1.96)\sqrt{n(T^2/12)} \leq S_n \leq n(T/2) + (1.96)\sqrt{n(T^2/12)} .$$

This hypothesis was tested with data from 208 simulation runs. Various distributions were assumed for both travel and service times and various values were used for the number of vehicles, number of loading points, mean travel time, and mean loading time, as shown in Table III.

In each of the 208 tests, the hypothesis that the arrivals occurred in accordance with a Poisson distribution was accepted at a 95 per cent level of significance. From these tests we conclude that the transfer vehicles are arriving at the loading area in accordance with a Poisson distribution. Furthermore, there is no indication that the Poisson nature of the arrivals in this system is dependent upon the underlying distributions of travel time and service time. We have not examined a large number of distribution functions, but those we have examined include the rather extreme cases of the uniform distribution on the one hand and a constant value on the other. Although no skewed distributions were tested, it appears that the assumption that the arrivals occur in accordance with a Poisson distribution is a robust assumption.

TABLE III

Distributions and Parameter Values
Employed in Hypothesis Testing

Distribution of Service Time	Exp.	Exp.	Exp.	Exp.	Uniform
Distribution of Travel Time	Exp.	Exp.	Constant	Uniform	Exp.
Mean Loading Time	0.33 Hr. 0.67 Hr. 1.00 Hr. 1.33 Hr.	0.50 Hr.	0.33 Hr. 0.67 Hr. 1.00 Hr.	0.33 Hr. 0.67 Hr. 1.00 Hr.	0.25 Hr. 0.50 Hr. 0.75 Hr. 1.00 Hr.
Mean Travel Time	0.06 Hr. 0.12 Hr. 0.25 Hr. 0.50 Hr. 1.00 Hr. 2.00 Hr. 4.00 Hr.	1.00 Hr.	0.12 Hr. 0.25 Hr. 0.50 Hr. 1.00 Hr. 2.00 Hr.	0.50 Hr.	0.12 Hr. 0.25 Hr. 0.50 Hr. 1.00 Hr. 2.00 Hr.
Number of Loading Points	4	1 2	4	4	4
Number of Vehicles	8,12,16	2,3,4 5,6	8,12,16	8,12,16	8,12,16
Number of Simulation Runs	84	10	45	9	60

Testing an Hypothesis on the Mean Arrival Rate.

Having accepted the hypothesis that arrivals at the loading area are occurring in accordance with a Poisson distribution, it next seemed desirable to make some determination concerning the mean value of this process. Intuitively, the mean arrival rate at the loading area should be the number of vehicles in the system divided by the average round-trip time, where the average round-trip time is taken to be the sum of the mean loading time, the mean unloading time, twice the mean travel time, the mean waiting time in the queue at the loading area, and the mean waiting time at the unloading area. If a Poisson process is observed until a predetermined number of events (in this case arrivals) have occurred, then the amount of observation time, W_n, required to observe the n events can be used to test hypotheses concerning the mean value of the process.[10] We shall denote the mean value by M and the hypothesized mean value by M_0. In order to avoid the transient period at the start of system operation, the measurement was made for 60 arrivals beginning at arrival number 400. If the events being observed are of the Poisson type, then $2MW_n$ is chi-square distributed with 2n degrees of freedom. We shall accept the hypothesis that the mean value of the process is the hypothesized value M_0 if the following inequalities are satisfied:

$$\frac{\chi^2_{\alpha/2}\ (2n)}{2M_0} \leq W_n \leq \frac{\chi^2_{1-\alpha/2}\ (2n)}{2M_0} \quad .$$

This test was made on data from the same 208 simulation runs as described previously (Table III), and the hypothesis was accepted at a 95 per cent significance level on all but one of the 208 runs. (The one case in which the hypothesis was rejected appears to have been a statistical quirk, since it did not occur at an extreme value

or under any unusual conditions.) We conclude that the vehicles cycling through the system are arriving at the loading area at a mean rate equal to the number of vehicles in the system divided by the average round-trip time, where the average round-trip time is the sum of the mean loading time, the mean unloading time, twice the mean travel time, the mean waiting time in the loading queue, and the mean waiting time in the unloading queue. Furthermore, there is no evidence from the simulation data that this mean arrival rate is affected by the underlying distribution of travel time or service time.

Significance.

We have accepted the hypothesis that, in the simulation model, arrivals at the loading area occur in accordance with a Poisson distribution, and we have accepted the hypothesis that the mean arrival rate at the loading area is determined by the number of vehicles in the system divided by the average round-trip time for a vehicle. We have tested these hypotheses over the range of values shown in Table III. There is no indication that these results are dependent on the assumed distribution of the travel times or the service times. Although these results throw some light on the nature of the process being investigated, they do not, of themselves, lead to an immediate closed form solution. The mean arrival rate, which is the parameter of the Poisson distribution, is not independent of, but rather depends upon the waiting times in the system. The waiting times are themselves dependent upon the arrival rate. Thus, if we knew either the arrival rate or the waiting times we could readily solve the system with closed form queueing equations and determine the values of the other. Before the fact, however, we do not know what the values will be for either the

mean arrival rate or the waiting times. Use of the equations developed in Chapter IV, however, will enable us to estimate the average queueing time per vehicle round trip and the total time required to complete the landing of a given tonnage of cargo.

Up to this point we have been assuming that the fleet of transfer vehicles is composed entirely of one type of vehicle. Some of the complexities that arise in the case of mixed vehicle fleets will be examined in the next chapter.

CHAPTER VI

IMPLICATIONS OF MIXED TRANSFER VEHICLE FLEETS

We have on several occasions mentioned the fact that, in actual operations, our fleet of transfer vehicles consists of a variety of vehicle types rather than just one type. This is certainly true today, and seems likely to be the case in the future, due to the tactical problems that must be solved in the assault phase of any amphibious operation. Since this is so, it appears desirable to investigate the mixed transfer vehicle case, and our simulation provides a ready means for doing so.

Fleets Composed of Vehicles with Differing Payloads.

One of the situations that is of considerable interest is the case of a fleet of transfer vehicles of the same speed, but with differing payloads. This is the situation that exists between various types of present-day landing craft (LCU's, LCM's, LCVP's). The speed differential is not significant, but there is a significant difference in the payloads of the various landing craft mentioned.

We will consider two fleets of vehicles all having a speed of ten knots. In one fleet, half of the vehicles will have a fifteen-ton payload and the remainder a five-ton payload. In the other fleet, half of the vehicles will have a fifteen-ton payload and the remainder a ten-ton payload. When a number of vehicles are in the queue waiting to load or to unload, we will have a choice as to what type of vehicle to load or to unload first. One of our primary objectives in this portion of the study will be to determine an optimal decision rule for making this choice. Three possible decision rules which will be investigated are:

1) load and unload the smaller payload vehicles first,

2) load and unload the larger payload vehicles first, and

3) choose vehicles in some random fashion for loading and unloading.

In order to test these decision rules, the basic simulation program was modified slightly to include the decision rule as part of the simulation. In the basic simulation program, whenever a vehicle is to be brought from a queue into a loading or unloading point, the program searches through an array in which the staus of all vehicles is stored until it finds a vehicle whose status number indicates that that vehicle is in the loading or the unloading queue, as appropriate. Each vehicle has an index number in the sinulation. Among the vehicles in the queue, the simulation program always selects the vehicle with the lowest index number first. If the decision rule being tested was to load the smaller payload vehicles first, the payload assigned to the vehicles with the lower index numbers was the smaller payload, and vice versa if the decision rule being tested was to load the larger vehicles first. Whenever a vehicle arrives and goes directly into a loading or an unloading point, its index number and hence its payload is known. When the decision rule being tested was to select vehicles according to some random procedure, even numbered vehicles were assigned one payload and odd numbered vehicles were assigned the other payload.

In comparing the results achieved under the different decision rules, non-parametric or distribution free statistical tests were used. The sign test and the signed rank test were selected.[9] The hypothesis tested was the hypothesis of no difference between the results. Data were used only from combinations of parameter values that produced average waiting times greater than 0.10 hour. When the average waiting time

is less than 0.10 hour per round trip, the decision rule is not playing an important role, since there is usually no queue or only one vehicle in the queue, and hence no choice exists as to which type of vehicle to load or to unload first. The data are shown in Table IV.

In the case of the transfer vehicle fleet where half the vehicles had a fifteen-ton payload and half had a five-ton payload, the results obtained using the decision rule to load or unload the smaller vehicle first were tested against the other two decision rules described above. Using the signed rank test, the hypothesis of no difference in the results was rejected in both cases at the five per cent significance level. For the case of the fleet composed half of vehicles with a fifteen-ton payload and half of vehicles with a ten-ton payload, the results showed generally smaller differences, but again the hypothesis of no difference was rejected in both cases at the five per cent significance level.

Other things being equal, larger payload vehicles (employed as pure fleets) are more efficient than smaller payload vehicles in that they move a fixed tonnage of cargo in a shorter period of time, as we have seen in Chapter IV. In considering the mixed fleet of vehicles, however, we conclude that we can improve the operation of the system by using the decision rule to load the smaller vehicles first when there is a choice, rather than loading and unloading the larger vehicles first or choosing vehicles at random. This improvement is apparently due to better utilization of the loading and unloading points. It should be borne in mind, however, that no allowance was made for buffer time in the simulation. In comparing the decision rule as applied to the fleet with fifteen-ton and five-ton vehicles, using the sign test, we would reject the hypothesis that loading and unloading the smaller vehicles

TABLE IV

Time Required to Unload Ten Thousand Tons of Cargo with a Mixed Fleet of Transfer Vehicles: Comparison of Decision Rules When Half the Vehicles Have the Larger Payload and Half Have the Smaller

Payload of Smaller Vehicle	Mean Travel Time	Number of Vehicles	Choose 15 Ton Vehicles First	Choose Vehicles at Random	Choose Smaller Vehicles First
5 Tons	0.12 Hr.	12	207 Hrs.	197 Hrs.	190 Hrs.
5	0.12	16	198	193	183
5	0.25	12	217	209	200
5	0.25	16	197	207	186
5	0.50	12	237	232	228
5	0.50	16	210	211	204
5	1.0	16	232	244	239
10 Tons	0.12 Hr.	8	220 Hrs.	216 Hrs.	219 Hrs.
10	0.12	12	197	193	188
10	0.12	16	190	190	180
10	0.25	8	230	242	235
10	0.25	12	207	198	187
10	0.25	16	183	188	185
10	0.50	12	213	210	207
10	0.50	16	197	191	194
10	1.0	12	259	253	261
10	1.0	16	213	214	214
10	2.0	16	300	299	288

first produced a five per cent reduction in time compared to the decision rule to load the larger vehicles first, but we would accept the hypothesis of a three per cent reduction. In percentage terms, the improvement is small, but the cost of implementing the decision rule is negligible.

Fleets Composed of Vehicles with Differing Speeds.

Another case we wish to consider is that of a mixed fleet in which the transfer vehicles all have the same payload but have differing speeds. The procedure will be generally the same as that described above. The parameter values used and the results obtained from the simulation runs are shown in Table V. Using the sign test, we would accept they hypothesis that there is no difference between the decision rules at the five per cent significance level but we would reject the hypothesis at the ten per cent significance level. If the two decision rules we have considered do make any difference in the overall performance of the system under these conditions, this difference is apparently on the order of one per cent or less. Thus, we conclude that if the fleet of transfer vehicles consists of vehicles with equal payloads but different speeds, it does not make much difference whether we load the faster vehicles first or the slower vehicles first.

Interpretation and Significance of the Results.

In employing mixed fleets of transfer vehicles, it is apparent that part of the doctrine for their employment (the decision rules considered here) can play an important role in the overall system performance in terms of time required to complete unloading. We have examined in detail just two of the numerous situations that might arise in practice. However, for any given situation the computer simulation can

TABLE V

Time Required to Unload Ten Thousand Tons of Cargo with a Mixed Fleet of Transfer Vehicles: Comparison of Decision Rules When Half the Vehicles Have a Speed of Ten Knots and Half Have a Speed of Twenty Knots

Mean Loading Time	Mean Travel for Slower Vehicles	Number of Vehicles	Choose 20 Knot Vehicles First	Choose 10 Knot Vehicles First
0.33 Hr.	0.12 Hr.	12	188 Hrs.	191 Hrs.
0.33	0.12	16	184	185
0.33	0.25	12	202	206
0.33	0.25	16	185	186
0.33	0.50	16	200	210
0.67	0.12	8	220	221
0.67	0.12	12	194	184
0.67	0.12	16	170	187
0.67	0.25	8	232	229
0.67	0.25	12	195	194
0.67	0.25	16	177	184
0.67	0.50	12	208	212
0.67	0.50	16	179	183
0.67	1.0	12	237	245
0.67	1.0	16	199	212
0.67	2.0	16	263	268

readily be modified to reflect that situation and to test the results obtained by using alternative decision rules. The results are not obvious or easily obtainable by other means. Use of the simulation to determine the optimal decision rule appears to be a necessary part of the analysis whenever we are faced with the problem of attempting to optimize or to improve upon an existing system which includes a mixed fleet of transfer vehicles. It would be hazardous to attempt to extrapolate the results obtained outside the range of values actually tested, but the simulation provides a ready means for testing various decision rules applied to any actual combination of vehicles.

In dealing with the larger problem of designing a ship offloading system, additional complexities are introduced by considerations of mixed fleets of transfer vehicles. From a cost effectiveness point of view, an optimal system might well be a system using a mixed fleet of transfer vehicles. By optimal we mean a system that would achieve a minimum unloading time for a given cost or a minimum cost for a given unloading time. To illustrate why a mixed fleet may be optimal, we will consider three cases,

1) a pure fleet composed of twelve vehicles with five-ton payloads,
2) a pure fleet composed of twelve vehicles with fifteen-ton payloads, and
3) a mixed fleet composed of six vehicles with five-ton payloads and six vehicles with fifteen-ton payloads.

The mixed fleet will be operated according to the optimal decision rule of loading and unloading the smaller payload vehicles first whenever there is a choice. The data resulting from these tests are displayed in Table VI. Fifteen different combinations of parameter values

TABLE VI

Time Required to Unload Ten Thousand Tons of Cargo: Comparison of Simulation Results Achieved by Two Pure Fleets and a Mixed Fleet

Mean Travel Time	Number of Vehicles	Pure Fleet of 5 Ton Vehicles	Mixed Fleet, Half 5 Ton Vehicles Half 15 Ton Vehicles	Pure Fleet of 15 Ton Vehicles
0.12 Hr.	8	243 Hrs.	230 Hrs.	233 Hrs.
0.12	12	196	190	186
0.12	16	185	183	176
0.25	8	292	260	235
0.25	12	218	200	189
0.25	16	188	186	185
0.50	8	417	317	261
0.50	12	287	228	197
0.50	16	228	204	182
1.0	8	661	460	334
1.0	12	444	289	237
1.0	16	346	239	200
2.0	8	1154	700	491
2.0	12	770	445	341
2.0	16	592	360	263

were considered. The pure fleet of fifteen-ton vehicles achieved an average reduction in unloading time of 29.6 per cent as compared to the pure fleet of five-ton vehicles. The mixed fleet, however, did almost as well, achieving an average reduction in time of 20.5 per cent as compared to the pure fleet of five-ton vehicles. A mixed fleet of twelve vehicles, consisting of six five-ton vehicles and six fifteen-ton vehicles, was clearly superior in these simulation runs to a pure fleet of eight fifteen-ton vehicles but inferior to a pure fleet of twelve fifteen-ton vehicles. The twelve vehicle mixed fleet would be equivalent to a pure fleet of nine, ten or eleven of the fifteen-ton vehicles. Depending on the cost functions involved, it might well be that the mixed fleet would be the most cost-effective. This possibility introduces considerable additional complexity to the already complex problem of designing a general unloading system. It appears at this point that a reasonable approach would be to use the procedure outlined in Chapter IV to arrive at a cost-effective system employing a pure fleet, then test the implications of switching to a mixed fleet of transfer vehicles.

CHAPTER VII

SUMMARY, SUGGESTED EXTENSIONS, AND GENERAL APPLICABILITY

The design of an efficient system for the general unloading phase of an amphibious operation involves complex inter-relationships among a large number of variables. We have examined six of these variables, namely transfer vehicle speed and payload, the number of transfer vehicles in the system, ship-to-shore distance, and the number and capacity of loading and unloading points. The queueing problems that arise in the operation of this system play a highly significant role in overall system performance and hence must be taken into account.

Due to the circular nature of the system we are attempting to model, closed form solutions are not readily attainable. We have structured a model and developed a computer simulation by means of which the general unloading phase of an amphibious operation may be studied. Utilizing data generated by the computer simulation, we have examined some of the relationships between the variables in the system and we have developed an approximating equation for the time required to complete the unloading of a given tonnage of cargo. We have also investigated the impact of various hypothetical distributions of service time and travel time. The Poisson distribution of the arrivals does not appear to be dependent upon the underlying distributions of service time or travel time. The mean arrival rate, which is the parameter of the Poisson distribution, depends upon the mean values of service time and travel time, but does not appear to be dependent upon the probability distribution of service time or travel time. We have also examined the system when mixed fleets of transfer vehicles are employed. For two cases likely to arise in practice, we have compared the results obtained

using different decision rules as to which vehicles to load or unload first.

There are several different levels at which we may be interested in applying the results of this paper. For convenience, we will discuss them in terms of the short-run time period, the mid-range time period, and the long-run time period. In the short run we may be faced with an existing sytem, in which case our only recourse is to employ the most effective decision rule in operating the system. We have illustrated how a system employing a mixed fleet of transfer vehicles can be analyzed in order to achieve the best possible results with fixed resources. In the context of operational planning, we have outlined how the approximating formula or the computer simulation itself may be used to obtain estimates of the performance of a given system.

In applications pertaining to the mid-range time period from five to ten years hence, we may be faced with the task of determining the best means of improving upon an existing system or we may be faced with the task of choosing among a number of alternative systems. In Chapter IV we outlined procedures for dealing with these situations.

In the long run we are free to modify all of the variables under consideration. This presents us with by far the most complicated problem. We have defined an efficient system to be a system in which the ratio of marginal return (in time reduction) to marginal cost is the same for each of the variables. We have mentioned some of the practical and theoretical problems involved in trying to find such efficient points. Nevertheless, the step-by-step procedure we have outlined in Chapter IV appears to be the best practical approach to achieving an efficient system design.

Prior to implementing the results developed in this paper, it would be necessary to test the entire model by comparing the results predicted by the model with results achieved in actual operations. It would also be necessary to determine the actual parameter values to be used. This should be accomplished by field experimentation under realistic operating conditions. It appears that accurate estimates of the parameter values for loading and unloading time and for travel time are more important than the probability distributions associated with those times.

Ship characteristics determine the number and capacity of the loading points in the system which we have modeled. Lead times for ship design and construction are such that the characteristics of the ships that will be available five to ten years in the future are fairly well known today. Thus we might reasonably be able to fix the number and capacity of loading points that will be available in a "typical" task force in the time period five to ten years hence. With appropriate cost data, and after validation of the model, it should be possible to develop transfer-vehicle fleets that meet our definition of an efficient system for those variables not considered fixed. Unless some unexpected dominant transfer vehicle fleet emerges, it would probably be necessary to make separate analyses for various ship-to-shore distances. The implications of various ship-to-shore distances on system cost and performance could then be portrayed. Alternatively, it might be possible to assign a discrete probability mass function to the variable ship-to-shore distance and then to develop a transfer vehicle fleet that would be efficient in an expected value sense. That is, it would be efficient over a large number of operations if the various ship-to-shore distances occurred in accordance with the assigned probability mass function.

Another interesting extension would be to compare the performance of a system employing amphibian vehicles to move cargo from the ships to an inland dump and a system employing landing craft and trucks to accomplish the same task. The model and simulation we have developed can serve as the model of amphibian vehicles shuttling from a ship to an inland dump or as a model of landing craft shuttling from a ship to the waterline at the beach. A system employing landing craft and trucks to move cargo from a ship to an inland dump involves the interaction, at the beach, of two circular queueing systems such as the one we have modeled. A comparison of the relative effectiveness of a system employing amphibian vehicles and the system employing landing craft and trucks could then be made. This would be of considerable interest since a major tactical and logistical consideration in amphibious operations is to move men, equipment, and supplies rapidly inland and to avoid congestion on the beach itself.

This model and the accompanying computer simulation were developed in order to investigate the general unloading phase of an amphibious operation, but the model would be generally applicable to any closed system in which a fixed population cycles continually through the system. Many materials-handling systems and systems incorporating shuttling operations would appear to be of the same general nature and hence amenable to analysis by the same general methods and by the same sort of model and simulation.

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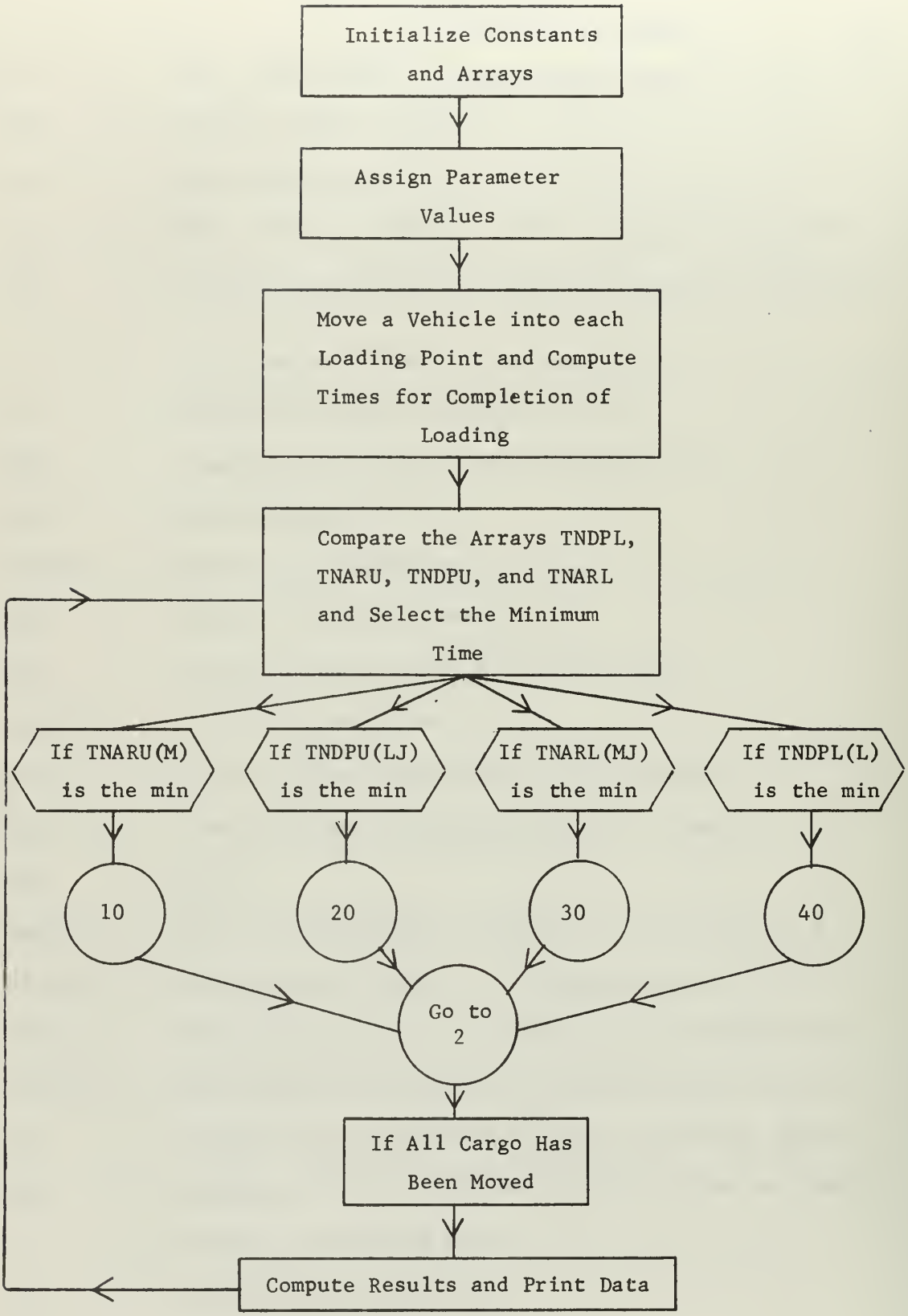
APPENDIX

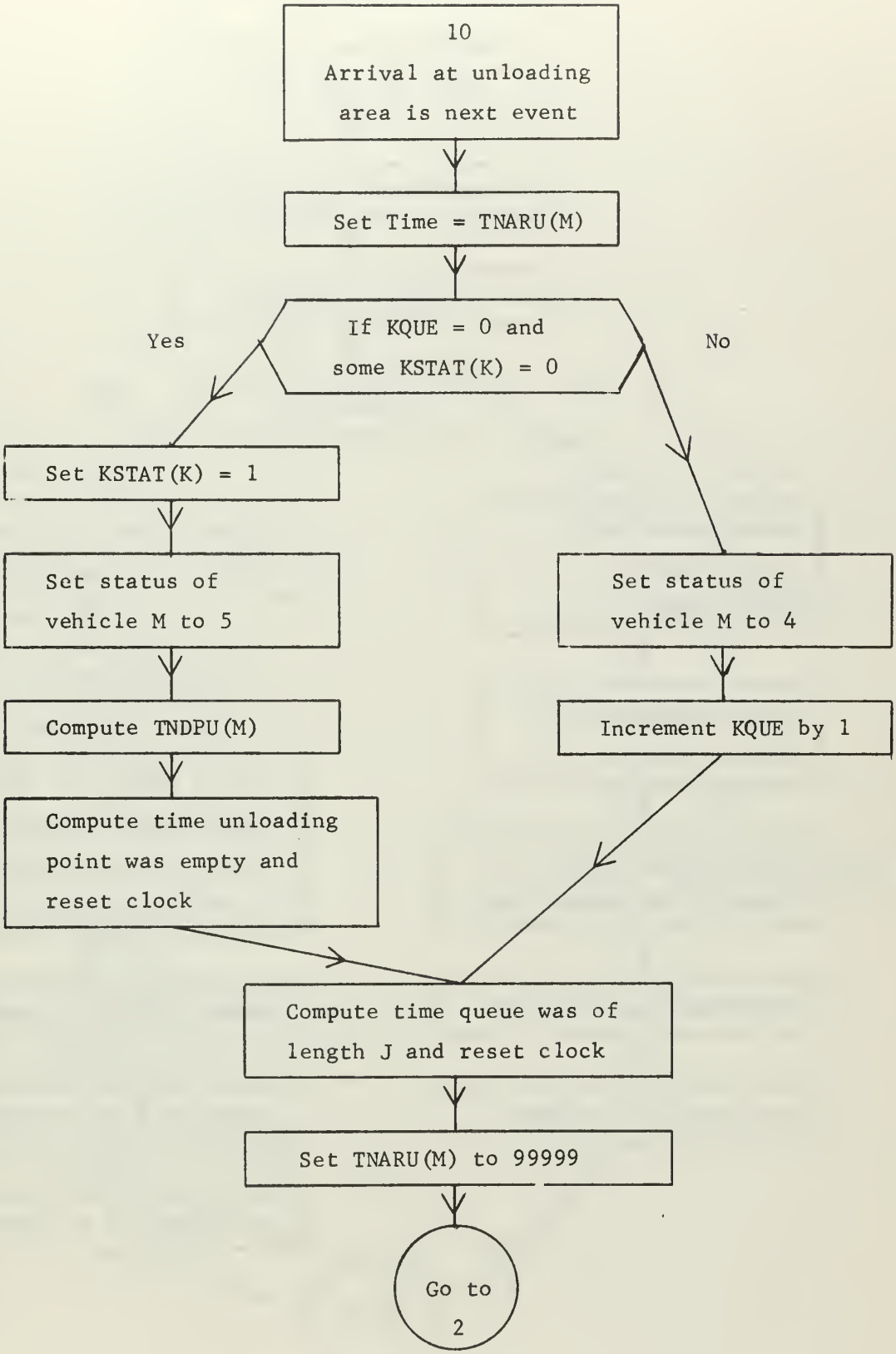
The simulation program was written in FORTRAN IV for the IBM 360/67 computer. This appendix includes a list of the variable names used in the program, generalized flow charts, and a computer print-out of the program.

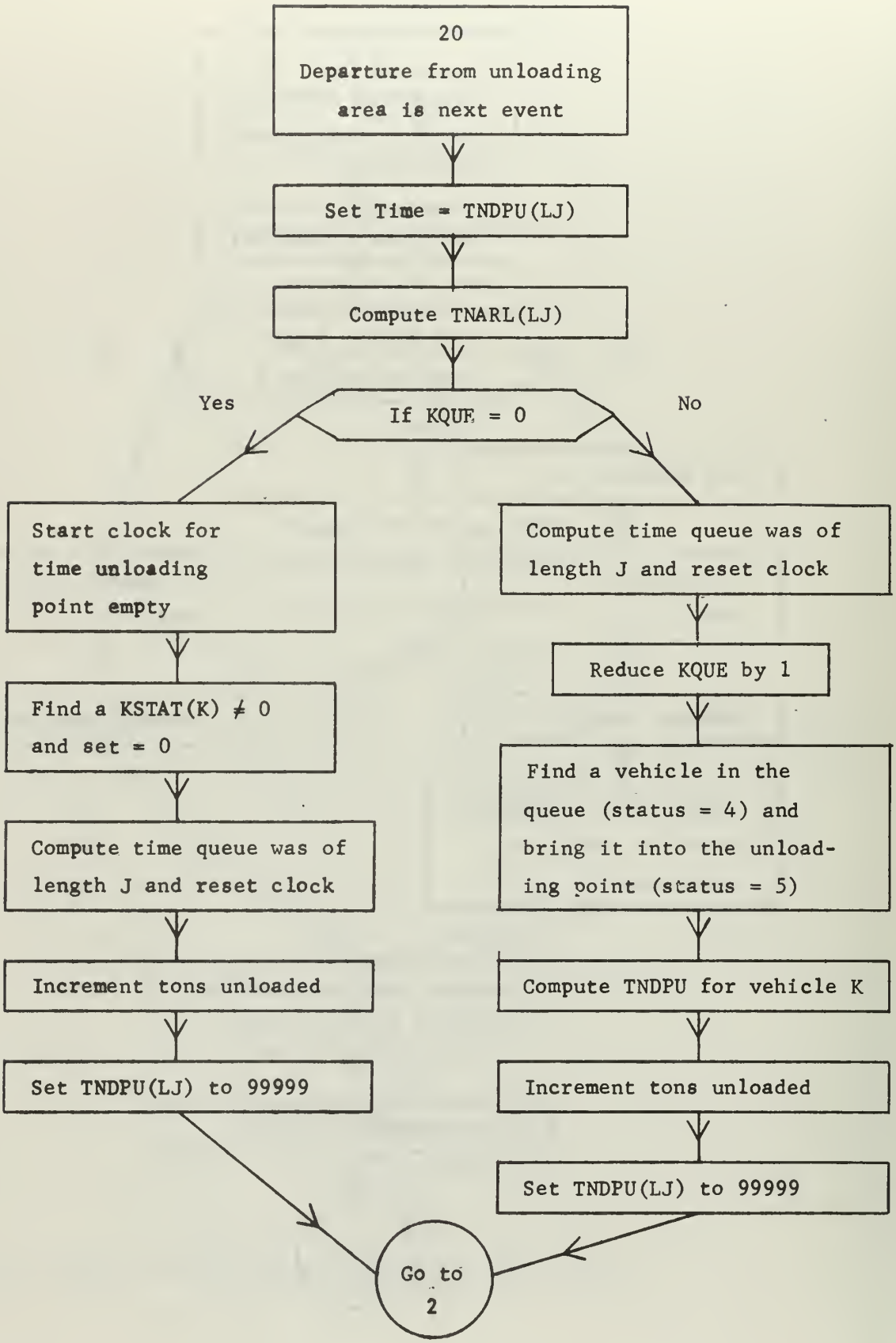
LIST OF VARIABLE NAMES

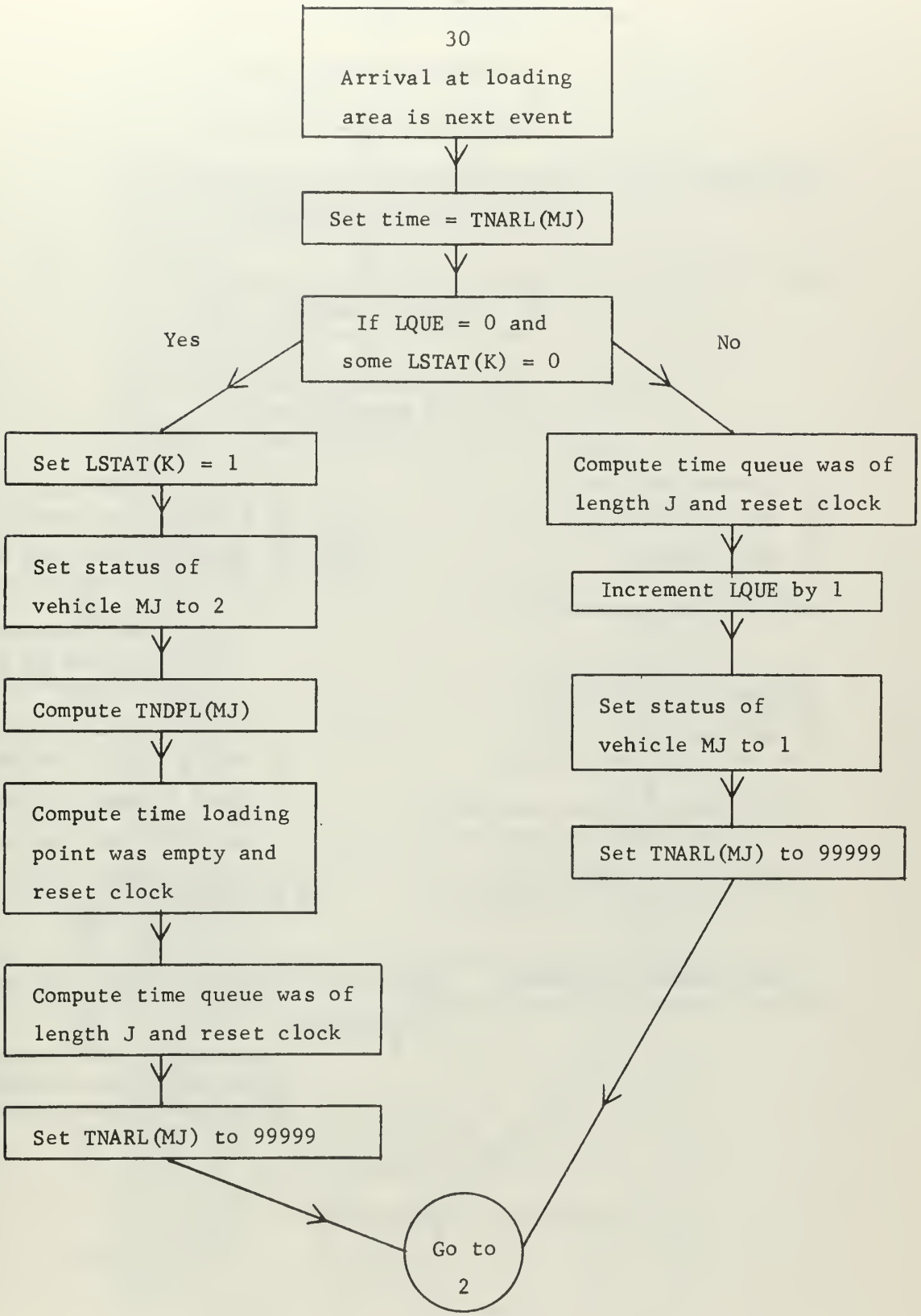
AL	Mean Loading Time
ALN	Transfer Vehicle Payload
AM	Mean Travel Time
AQL	Average Waiting Time per Vehicle Round Trip at Loading Area
AQU	Average Waiting Time per Vehicle Round Trip at Unloading Area
D	Total Number of Round Trips Required
KK	Number of Loading (Unloading) Points
KQUE	Length of the Queue at the Unloading Area
KS(K)	Status of Vehicle K
KSTAT(L)	Status of Unloading Point L
KVEH	Number of Transfer Vehicles
LQUE	Length of the Queue at the Loading Area
LSTAT(L)	Status of Loading Point L
QLL(J)	Length of Time Loading Queue Was of Length J
QLU(J)	Length of Time Unloading Queue Was of Length J
TIM	Time
TNARL(K)	Time of Next Arrival at Loading Area for Vehicle K
TNARU(K)	Time of Next Arrival at Unloading Area for Vehicle K
TNDPL(K)	Time Next Departure from Loading Area for Vehicle K
TNDPU(K)	Time Next Departure from Unloading Area for Vehicle K
TLE	Length of Time at Least One Loading Point Was Empty
TUE	Length of Time at Least One Unloading Point Was Empty
X	Clock for Unloading Queue
XX	Clock for Unloading Point
Y	Clock for Loading Queue

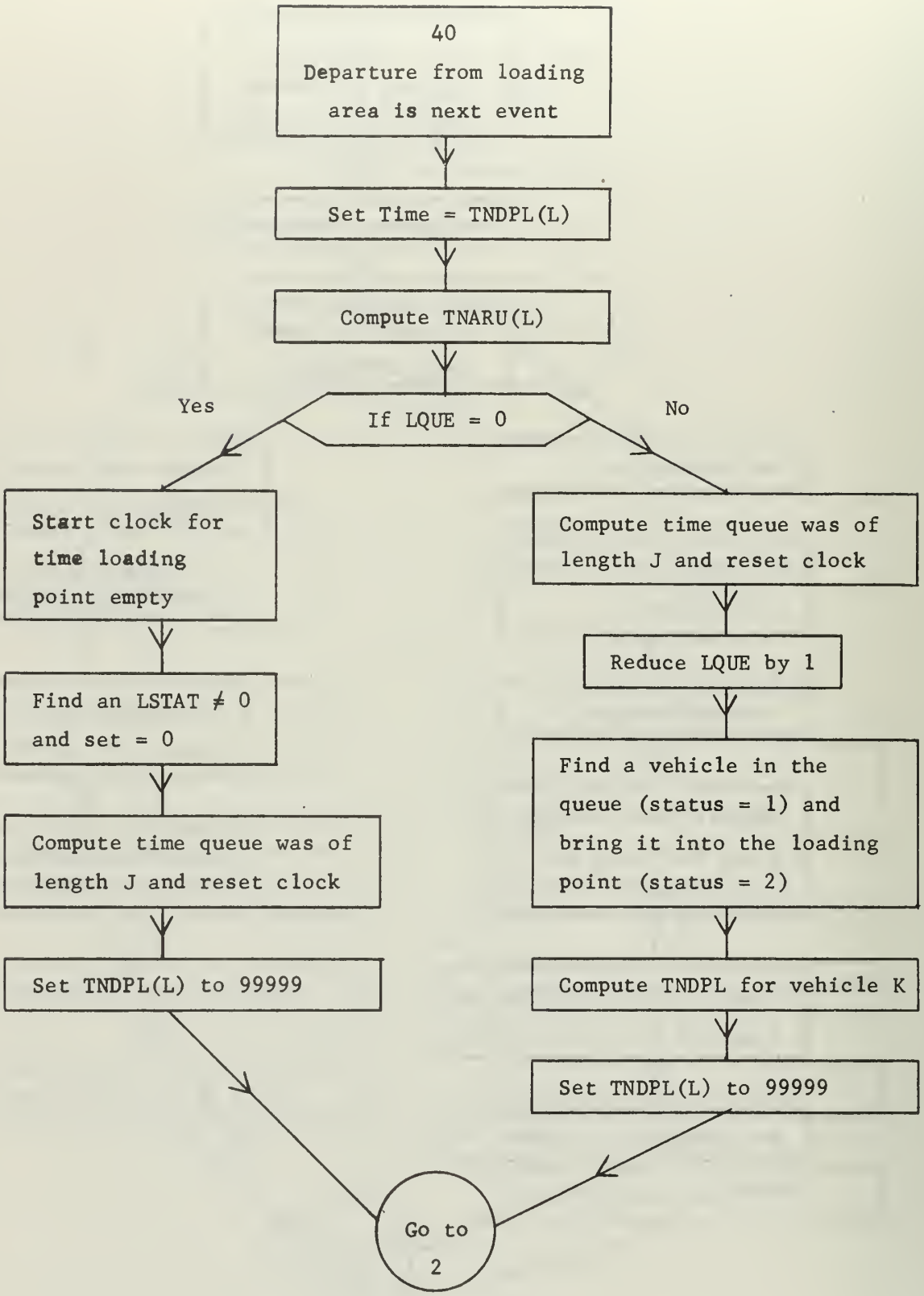
YY	Clock for Loading Point
Z	Tons of Cargo Moved


Initialize Constants and Arrays
Assign Parameter Values
Move a Vehicle into each Loading Point and Compute Times for Completion of Loading
Compare the Arrays TNDPL, TNARU, TNDPU, and TNARL and Select the Minimum Time
If TNARU(M) is the min
If TNDPU(LJ) is the min
If TNARL(MJ) is the min
If TNDPL(L) is the min
10
20
30
40
Go to 2
If All Cargo Has Been Moved
Compute Results and Print Data


10
Arrival at unloading area is next event
Set Time = TNARU(M)
If KQUE = 0 and some KSTAT(K) = 0
Yes
No
Set KSTAT(K) = 1
Set status of vehicle M to 5
Compute TNDPU(M)
Compute time unloading point was empty and reset clock
Set status of vehicle M to 4
Increment KQUE by 1
Compute time queue was of length J and reset clock
Set TNARU(M) to 99999
Go to 2


20
Departure from unloading area is next event
Set Time = TNDPU(LJ)
Compute TNARL(LJ)
If KQUE = 0
Yes
No
Start clock for time unloading point empty
Find a KSTAT(K) ≠ 0 and set = 0
Compute time queue was of length J and reset clock
Increment tons unloaded
Set TNDPU(LJ) to 99999
Compute time queue was of length J and reset clock
Reduce KQUE by 1
Find a vehicle in the queue (status = 4) and bring it into the unloading point (status = 5)
Compute TNDPU for vehicle K
Increment tons unloaded
Set TNDPU(LJ) to 99999
Go to 2


30
Arrival at loading area is next event
Set time = TNARL(MJ)
If LQUE = 0 and some LSTAT(K) = 0
Yes
No
Set LSTAT(K) = 1
Set status of vehicle MJ to 2
Compute TNDPL(MJ)
Compute time loading point was empty and reset clock
Compute time queue was of length J and reset clock
Set TNARL(MJ) to 99999
Compute time queue was of length J and reset clock
Increment LQUE by 1
Set status of vehicle MJ to 1
Set TNARL(MJ) to 99999
Go to 2


40
Departure from loading area is next event
Set Time = TNDPL(L)
Compute TNARU(L)
If LQUE = 0
Yes
No
Start clock for time loading point empty
Find an LSTAT ≠ 0 and set = 0
Compute time queue was of length J and reset clock
Set TNDPL(L) to 99999
Compute time queue was of length J and reset clock
Reduce LQUE by 1
Find a vehicle in the queue (status = 1) and bring it into the loading point (status = 2)
Compute TNDPL for vehicle K
Set TNDPL(L) to 99999
Go to 2

```
      DIMENSION QLL(50),QLU(50),TNDPL(50),TNDPU(50),
     1TNARU(50),TNARL(50),KSTAT(10),LSTAT(10),KS(50)
      IX = 123456789
      CALL RANDU (IX,IY,RN)
      IX = IY
C     INITIALIZE PARAMETERS AND ARRAYS FOR NEXT RUN
      KK = 4
      DO 103 IK = 1,4
      B = IK
      ALN = 5. * B
      AL = ALN / 15.
      DO 106 IJ = 1,7
      AM = ((1. / 32.) * 2. ** IJ)
      DO 59 I = 8,16,4
      JJ = I + 1
      DO 60 K = 1, JJ
      QLL(K) = 0.
      QLU(K) = 0.
      TNDPL(K) = 9999.
      TNDPU(K) = 9999.
      TNARL(K) = 9999.
      TNARU(K) = 9999.
      KS(K) = 1
   60 CONTINUE
      U = 0.
      SN = 0.
      UI = 0.
      TIM = 0.
      X = 0.
      Y = 0.
      XX = 0.
      YY = 0.
      TUE = 0.
      TLE = 0.
      KQUE = 0
      Z = 0.
      DO 62 K = 1, KK
      KSTAT(K) = 0
      LSTAT(K) = 0
   62 CONTINUE
      LQUE = 1
      DO 63 K = 1, KK
      CALL RANDU (IX,IY,RN)
      IX = IY
      R = (-AL * ALOG(RN))
   65 TNDPL(K) = TIM + R
      KS(K) = 2
      LSTAT(K) = 1
      LQUE = LQUE - 1
      IF(LQUE .EQ. 0) GO TO 2
   63 CONTINUE
    2 IF(Z .GE. 10000) GO TO 90
      L = 1
      DO 71 LK = 2, I
      IF(TNDPL(L) .LE. TNDPL(LK)) GO TO 71
      L = LK
   71 CONTINUE
      M = 1
      DO 72 MK = 2, I
      IF(TNARU(M) .LE. TNARU(MK)) GO TO 72
```

```
      M = MK
   72 CONTINUE
      LJ = 1
      DO 73 LK = 2,I
      IF(TNDPU(LJ) .LE. TNDPU(LK)) GO TO 73
      LJ = LK
   73 CONTINUE
      MJ = 1
      DO 74 MK = 2, I
      IF(TNARL(MJ) .LE. TNARL(MK)) GO TO 74
      MJ = MK
   74 CONTINUE
      IF(TNDPL(L) .GT. TNARU(M)) GO TO 3
      IF(TNDPL(L) .GT. TNDPU(LJ)) GO TO 4
      IF(TNDPL(L) .GT. TNARL(MJ)) GO TO 30
      GO TO 40
    3 IF(TNARU(M) .GT. TNDPU(LJ)) GO TO 4
      IF(TNARU(M) .GT. TNARL(MJ)) GO TO 30
      GO TO 10
    4 IF(TNDPU(LJ) .GT. TNARL(MJ)) GO TO 30
      GO TO 20
C     ARRIVAL AT UNLOADING AREA IS NEXT EVENT
   10 TIM = TNARU(M)
      IF(KQUE .NE. 0) GO TO 11
      DO 12 K = 1,KK
      IF(KSTAT(K) .NE. 0) GO TO 12
      CALL RANDU (IX,IY,RN)
      IX = IY
      R = (-AL * ALOG(RN))
   14 TNDPU(M) = TNARU(M) + R
      KSTAT(K) = 1
      KS(M) = 5
      TUE = TUE + (TNARU(M) - XX)
      XX = TNARU(M)
      J = KQUE + 1
      QLU(J) = QLU(J) + (TNARU(M) - X)
      X = TNARU(M)
      TNARU(M) = 9999.
      GO TO 2
   12 CONTINUE
   11 J = KQUE + 1
      QLU(J) = QLU(J) + (TNARU(M) - X)
      X = TNARU(M)
      KQUE = KQUE + 1
      TNARU(M) = 9999.
      KS(M) = 4
      GO TO 2
C     DEPARTURE FROM UNLOADING AREA IS NEXT EVENT
   20 TIM = TNDPU(LJ)
      CALL RANDU (IX,IY,RN)
      IX = IY
      R = (-AM* ALOG(RN))
      TNARL(LJ) = TIM + R
      KS(LJ) = 6
      IF(KQUE .EQ. 0) GO TO 21
      J = KQUE + 1
      QLU(J) = QLU(J) + (TIM - X)
      KQUE = KQUE - 1
      X = TIM
      DO 22 K = 1, I
      IF(KS(K) .EQ. 4) GO TO 23
   22 CONTINUE
   23 KS(K) = 5
      CALL RANDU (IX,IY,RN)
      IX = IY
```

```
      R = (-AL * ALOG(RN))
   27 TNDPU(K) = TIM + R
      TNDPU(LJ) = 9999.
      Z = Z + ALN
      GO TO 2
   21 XX = TNDPU(LJ)
      DO 24 K = 1,KK
      IF(KSTAT(K) .EQ. 0) GO TO 24
      KSTAT(K) = 0
      GO TO 25
   24 CONTINUE
   25 Z = Z + ALN
   29 J = KQUE + 1
      QLU(J) = QLU(J) + (TNDPU(LJ) - X)
      X = TNDPU(LJ)
      TNDPU(LJ) = 9999.
      GO TO 2
C     ARRIVAL AT LOADING AREA IS NEXT EVENT
   30 TIM = TNARL(MJ)
   36 IF(LQUE .NE. 0) GO TO 31
      DO 32 K = 1,KK
      IF(LSTAT(K) .NE. 0) GO TO 32
      CALL RANDU (IX,IY,RN)
      IX = IY
      R = (-AL * ALOG(RN))
   38 TNDPL(MJ) = TIM + R
      LSTAT(K) = 1
      KS(MJ) = 2
      TLE = TLE + (TIM - YY)
      YY = TIM
      J = LQUE + 1
      QLL(J) = QLL(J) + (TIM - Y)
      Y = TIM
      TNARL(MJ) = 9999.
      GO TO 2
   32 CONTINUE
   31 J = LQUE + 1
      QLL(J) = QLL(J) + (TIM - Y)
      Y = TIM
      LQUE = LQUE + 1
      TNARL(MJ) = 9999.
      KS(MJ) = 1
      GO TO 2
C     DEPARTURE FROM LOADING AREA IS NEXT EVENT
   40 TIM = TNDPL(L)
      CALL RANDU (IX,IY,RN)
      IX = IY
      R = (-AM* ALOG(RN))
      TNARU(L) = TIM + R
      TNDPL(L) = 9999.
      KS(L) = 3
      IF(LQUE .EQ. 0) GO TO 41
      J = LQUE + 1
      QLL(J) = QLL(J) + (TIM - Y)
      LQUE = LQUE - 1
      Y = TIM
      DO 42 K = 1, I
      IF(KS(K) .EQ. 1) GO TO 43
   42 CONTINUE
   43 KS(K) = 2
      CALL RANDU (IX,IY,RN)
      IX = IY
      R = (-AL * ALOG(RN))
   47 TNDPL(K) = TIM + R
      GO TO 2
```

```
 41 YY = TIM
    DO 44 K = 1 , KK
    IF(LSTAT(K) .EQ. 0) GO TO 44
    LSTAT (K) = 0
    GO TO 45
 44 CONTINUE
 45 J = LQUE + 1
    QLL(J) = QLL(J) + (TIM - Y)
    Y = TIM
    GO TO 2
 90 KVEH = I
    PRINT 91, TIM, KVEH, TLE,TUE
 91 FORMAT (//10X, ' TIME = ' ,F10.5, ' NO.VEH = ' ,I5,
   1' TLE = ' ,F10.5, ' TUE = ' ,F10.5)
    AQL = 0.
    AQU = 0.
    D = Z / ALN
    DO 61 J = 1,I
    A = J - 1
    AQL = AQL + QLL(J) * A
    AQU = AQU + QLU(J) * A
 61 CONTINUE
    AQL = AQL / D
    AQU = AQU / D
    PRINT 94, AQL, AQU
 94 FORMAT (//10X, ' AVG DELAY LOADING = ' ,F15.5,
   1 ' AVG DELAY UNLOADING = ' ,F15.5)
    PRINT 110,AM,AL
110 FORMAT(//10X, 'AM ' ,F10.5, ' AL ' ,F10.5)
    JJ = I + 1
    DO 105 J = 1, JJ
    QLU(J) = QLU(J) / TIM
    QLL(J) = QLL(J) / TIM
105 CONTINUE
    PRINT 92, ((QLL(J),QLU(J)), J = 1,JJ)
92  FORMAT (//10X,2F10.5)
59  CONTINUE
106 CONTINUE
103 CONTINUE
    RETURN
    END
```

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13. ABSTRACT

The general unloading phase of amphibious operations is examined with particular emphasis on the queueing problems that arise. A model is structured and a computer simulation is provided. Variables considered are the number of transfer vehicles and their speed and payload, the number and capacity of loading and unloading points, and the ship-to-shore distance. Basic relationships between the variables are examined and an approximating formula is developed for computing the time required to unload a given tonnage of cargo. Applications in operational planning, system modification, and total system design are outlined. The impact on system performance of various assumed distributions of travel time and loading time is discussed. For systems employing mixed fleets of transfer vehicles, some basic decision rules are developed as to which vehicles to load or unload first. Suggestions as to further research and as to the model's general applicability are included.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Simulation						
Amphibious Operations						

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